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Distributed Air Ground Traffic Management

Concept Element (CE) 11: Terminal Arrival Self-Spacing for Merging and in Trail Separation

Human Centered Decision Support Tools for Arrival Merging and Spacing

Outline

- Goals and objectives
- 3-D CSD and merging and spacing tools
- Simulation
  - Ground side tools
  - Procedures
  - Design
- Results
  - Performance
  - Questionnaires
  - Lessons learned
  - TLX Workload
- Conclusions

AATT DAG-TM Research Goals … CE-11

DAG-TM Philosophy/Goal
National airspace participants can be information suppliers and team member who collaborate at all levels of traffic management decision making process.

Operational Goal CE-11

"Appropriately equipped aircraft can be given clearance to merge with aircraft in another arrival stream, and/or to maintain in-trail spacing relative to a leading aircraft."

FAA's Safeflight 21
RTCA
- Applications sub-group
- FAA/Eurocontrol RFG

Nov. 03: Self-spacing on an FMS Arrival
August 04: Self-Merging and spacing with on multiple FMS arrivals

Scenario Events: Merging and Spacing

Concept: Speed clearances to approximately meet a runway schedule then tactical velocity vector merge & time history spacing guidance to fine tune.

Aircraft arrive at TRACON meter fixes within approximately 30 seconds of scheduled time. Assumption: Aircraft are scheduled so they do not have to absorb more than about 40 seconds of delay in the TRACON.

The meter fix schedule is based on the estimated time to fly to the runway threshold on an FMS trajectory.

Controllers + ground tools determine runway, sequence and schedule at the runway.

The feeder controller clears aircraft to descend on an FMS transition with a speed to meet the scheduled time of arrival (STA) at the runway threshold and optionally a lead aircraft & spacing interval.

The feeder controller clears unequipped aircraft to fly a speed to meet the STA at the runway threshold.

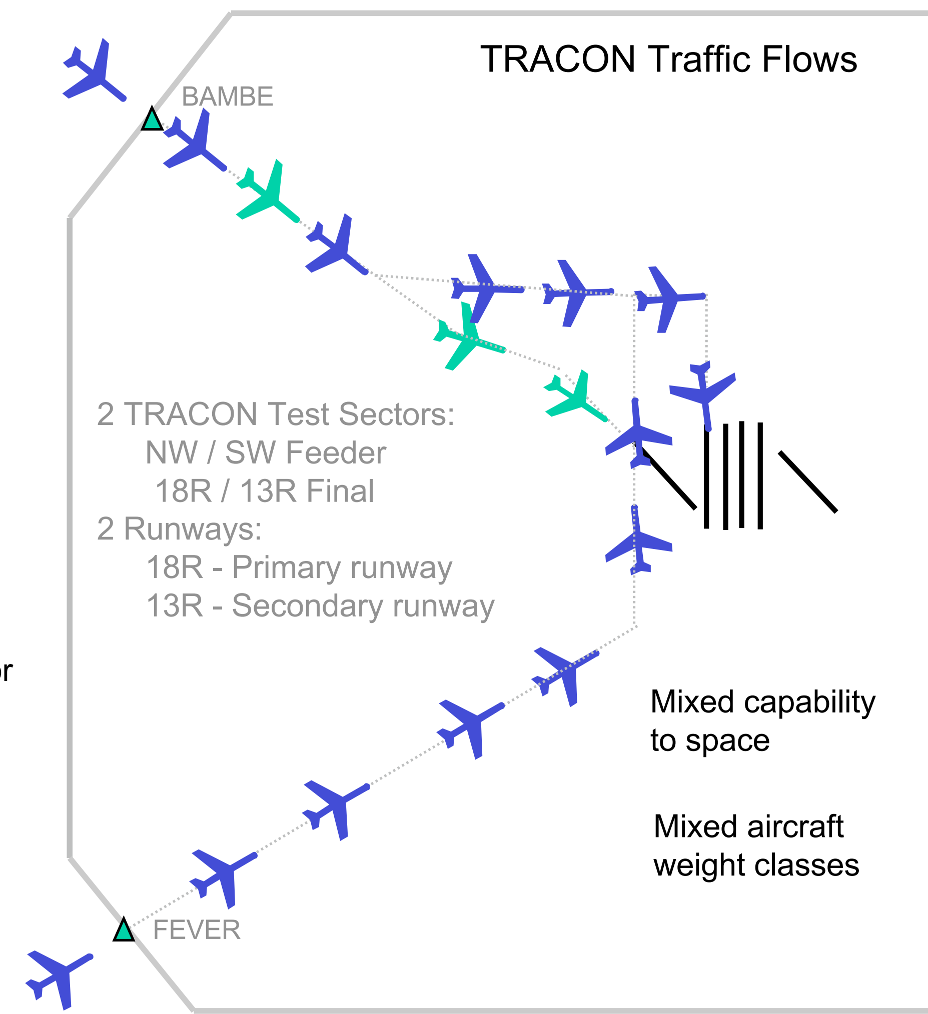
The final controller clears equipped aircraft to merge behind and then follow a designated lead aircraft. Spacing guidance is based on tactical velocity vector merge & time history spacing.

Controllers use spacing advisory tools to support conformance monitoring.

Spacing clearances terminate at a specified altitude above or a range to go to the runway.

Automatic information exchange:

- Broadcast aircraft ADS state.
- Broadcast FMS trajectory when it changes.



Single Pilot CDTI Instructions

Pilots will fly under ATC control for all scenarios.

Aircraft will start the scenarios 15 – 40 nm from the BAMBE or FEVER meter fixes.

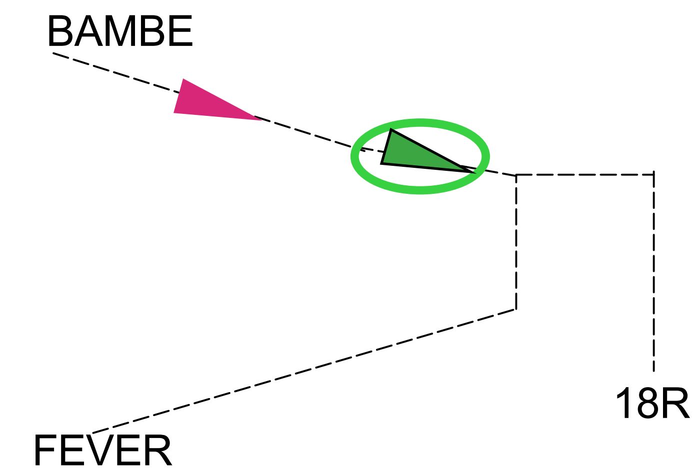
Pilots should allow their aircraft to fly & descend as predetermined by the program, even if Ownship appears to be following another aircraft too close (i.e., do not adjust speed or altitude unless commanded by ATC).

Pilots should check in with ATC 7nm before reaching the BAMBE or FEVER meter fix. If a pilot receives a datalink to contact ATC prior to 7nm, he or she should check in when the datalink is received.

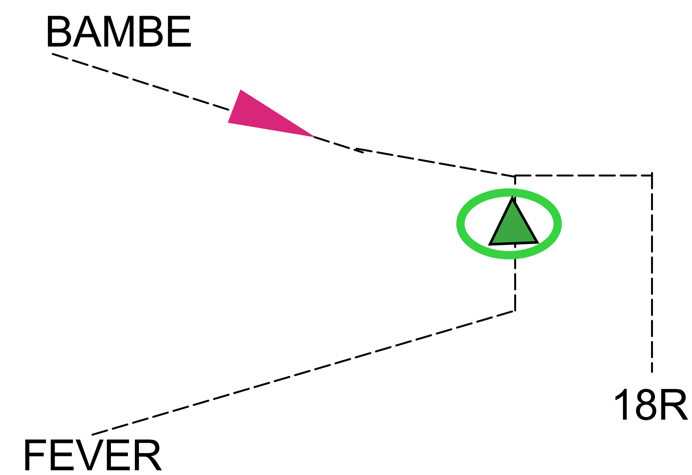
ALL NEW ATC CLEARANCES CANCEL ANY PREVIOUS CLEARANCES. For example, if a pilot is commanded to space off a lead aircraft, and the controller later asks Ownship to slow to 210kts, the pilot should cancel spacing and follow the new speed command.

Merging and/or spacing will occur after the meter fix.

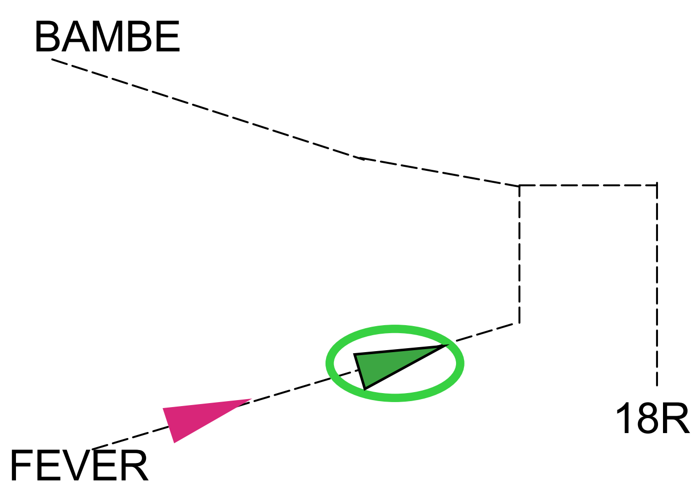
Merging and Spacing Flows



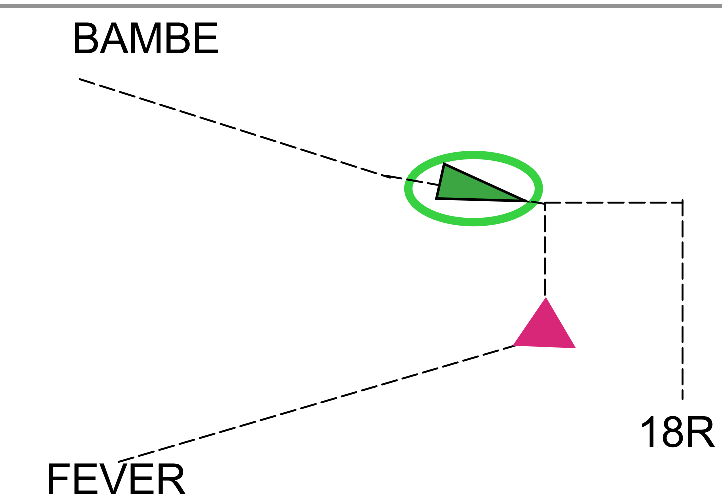
Enter through BAMBE, space off lead aircraft in BAMBE flow.



Enter through BAMBE, space off lead aircraft in FEVER flow.



Enter through FEVER, space off lead aircraft in FEVER flow.

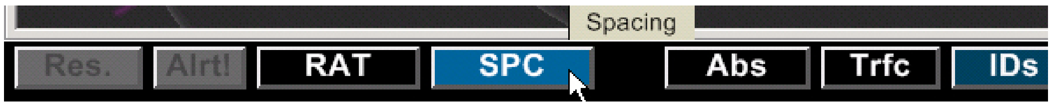


Enter through FEVER, space off lead aircraft in BAMBE flow.

Instructions for spacing

ATC will issue a clearance to either merge & space or space behind a designated lead aircraft.

1) Click the spacing button on the CDTI tool strip.



2) Click on the assigned lead aircraft

Click
lead AC

Right click to increase spacing interval, left click to decrease

3) Select the spacing interval specified by ATC.

4) Click the start button on the CDTI tool strip. Expect to wait for the software to arm. (e.g., if a 90-second spacing interval was selected, it may take up to 90 seconds for the software to arm. If a 120-second interval was selected, it may take 120 seconds for the software to arm). *Note: the spacing will "arm" faster if your aircraft is relatively close to the spacing parameter set.*

Instructions for spacing

5) The software will become “armed” for spacing.

At this point the spacing is armed (or ready), but the algorithms will not command the speed until spacing is “engaged”.

The spacing box may or may not appear at this point.

6) Select the spacing button on the MCP to engage spacing.

Click SPC

7) The software will engage spacing

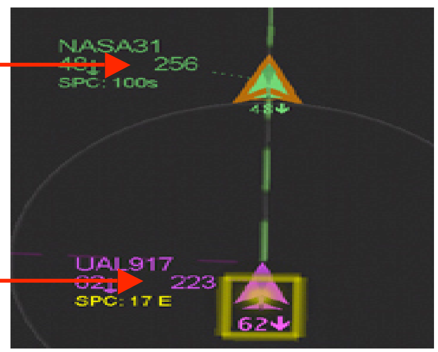
The algorithms will actively work to get the aircraft spaced based on the time specification.

Instructions for spacing

8) Monitor the spacing status of your aircraft

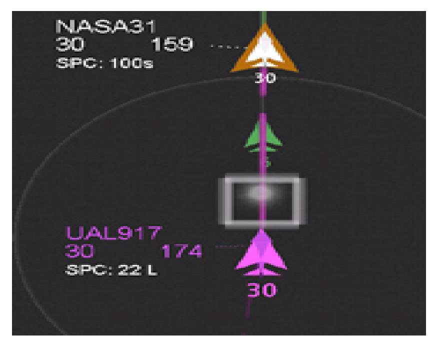
A **green box** indicates your aircraft is flying within the spacing limits specified.

Check commanded speeds



A **yellow box** indicates your aircraft is flying ahead of the limits specified. Your data tag will indicate how many seconds ahead your aircraft is flying. Verify that your aircraft is flying a slower commanded speed than the lead aircraft. If your aircraft is commanding a slower speed relative to the lead, it should eventually make it in “the box”.

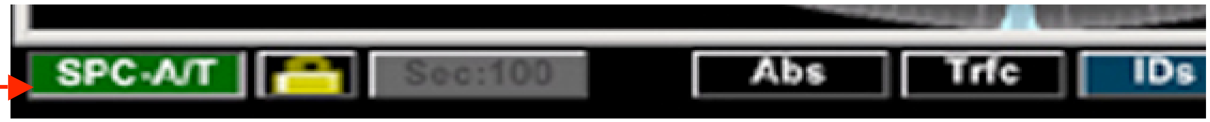
A **white box** indicates your aircraft is flying behind the spacing limit specified. Your data tag will indicate how many seconds behind your aircraft is flying. Verify that your aircraft is flying a faster commanded speed than the lead aircraft. If your aircraft is commanding a faster speed relative to the lead, it should eventually make it in “the box”.



Instructions for spacing

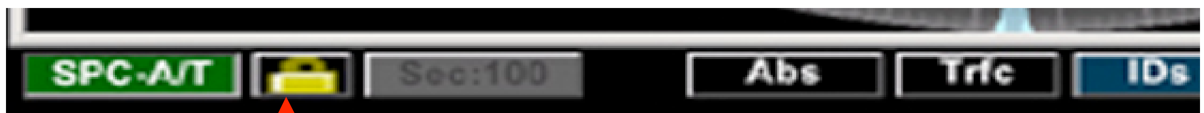
9) To cancel spacing, click the green spacing button on the CDTI tool strip.

Click to cancel



10) To unlock (or change) the current spacing value, click the lock icon on the CDTI tool strip. Then change the spacing interval and click start to reengage spacing with the newly specified time.

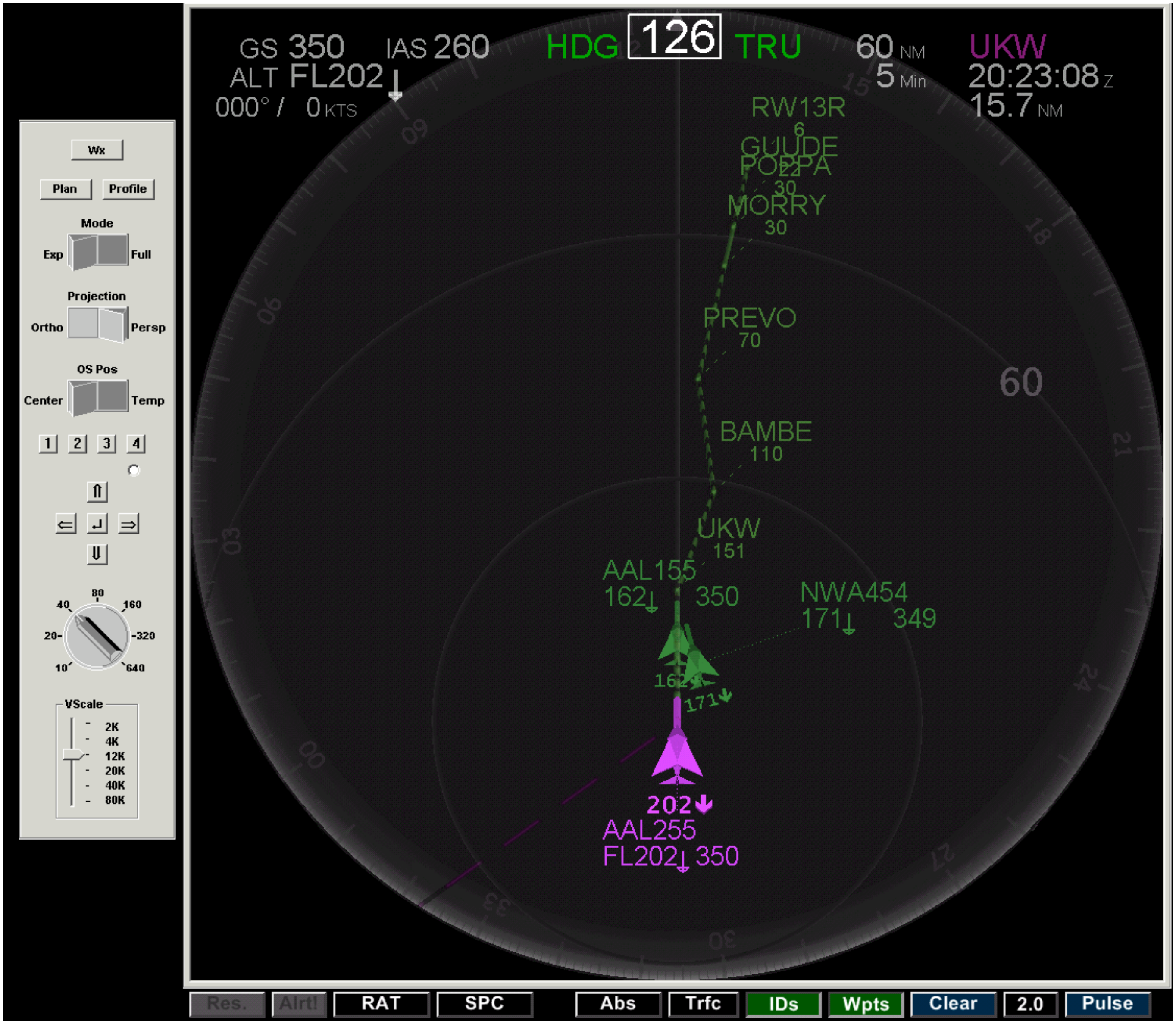
Click to change



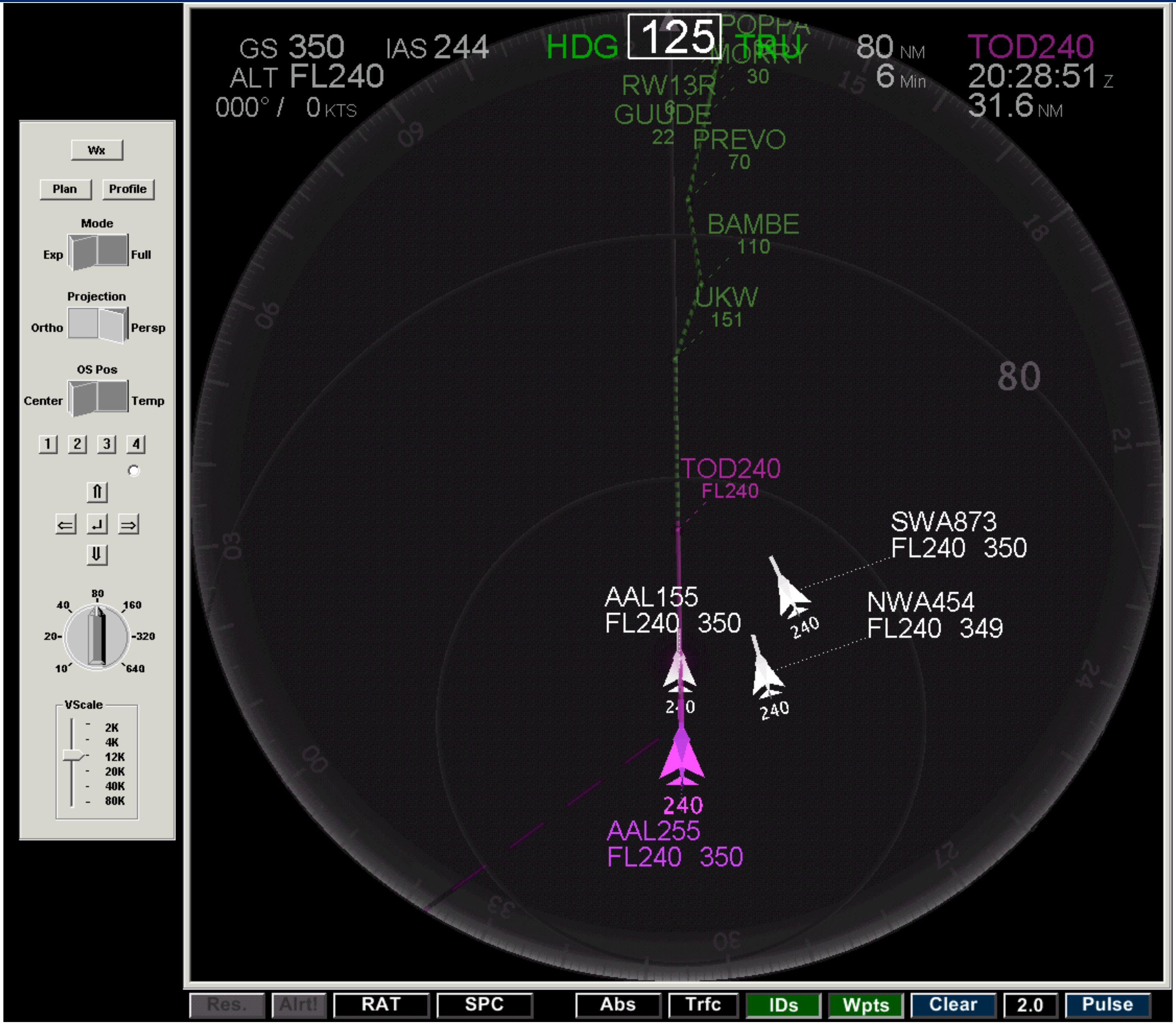
The flight deck spacing algorithm utilized in this simulation was developed at NASA LaRC, By Terry Abbott. However, the version used was not the latest version of the algorithm.

3-D Display of Approach Spacing

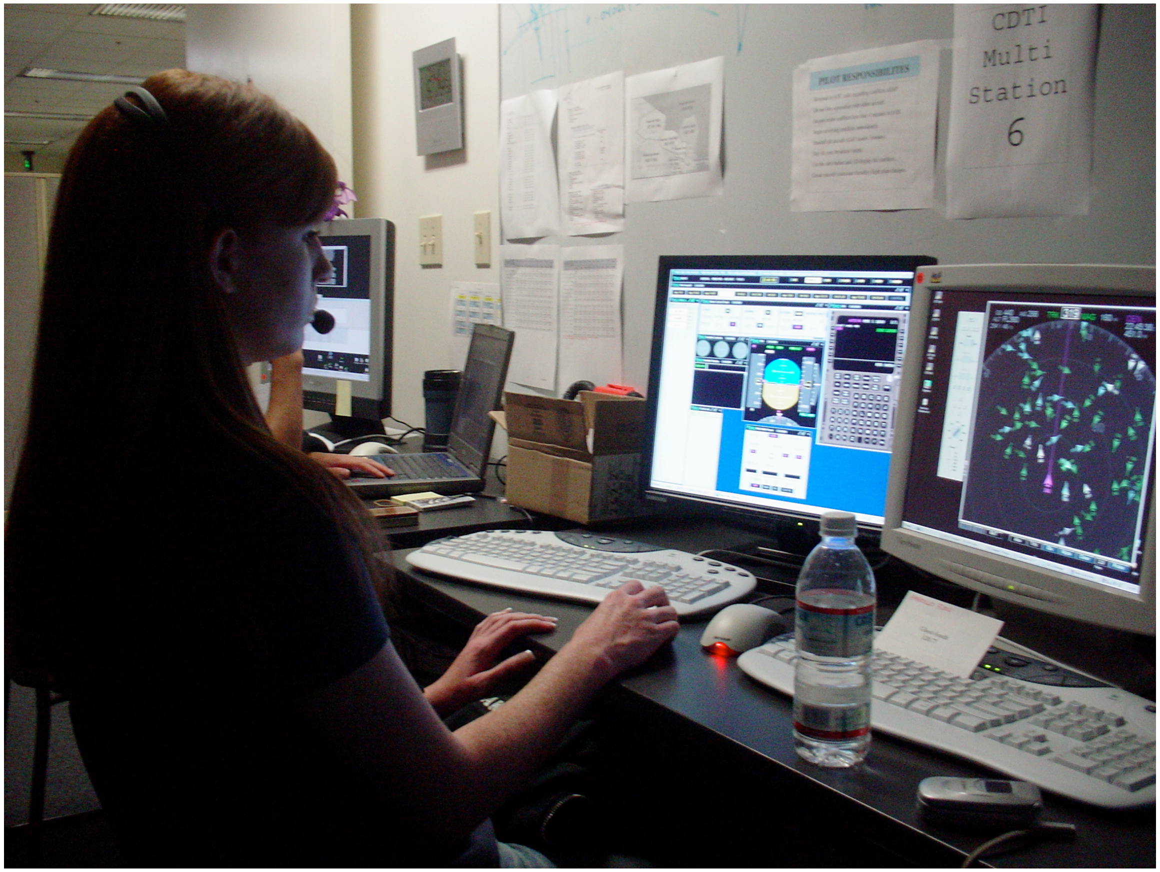
AATT **DAG-TM Research**



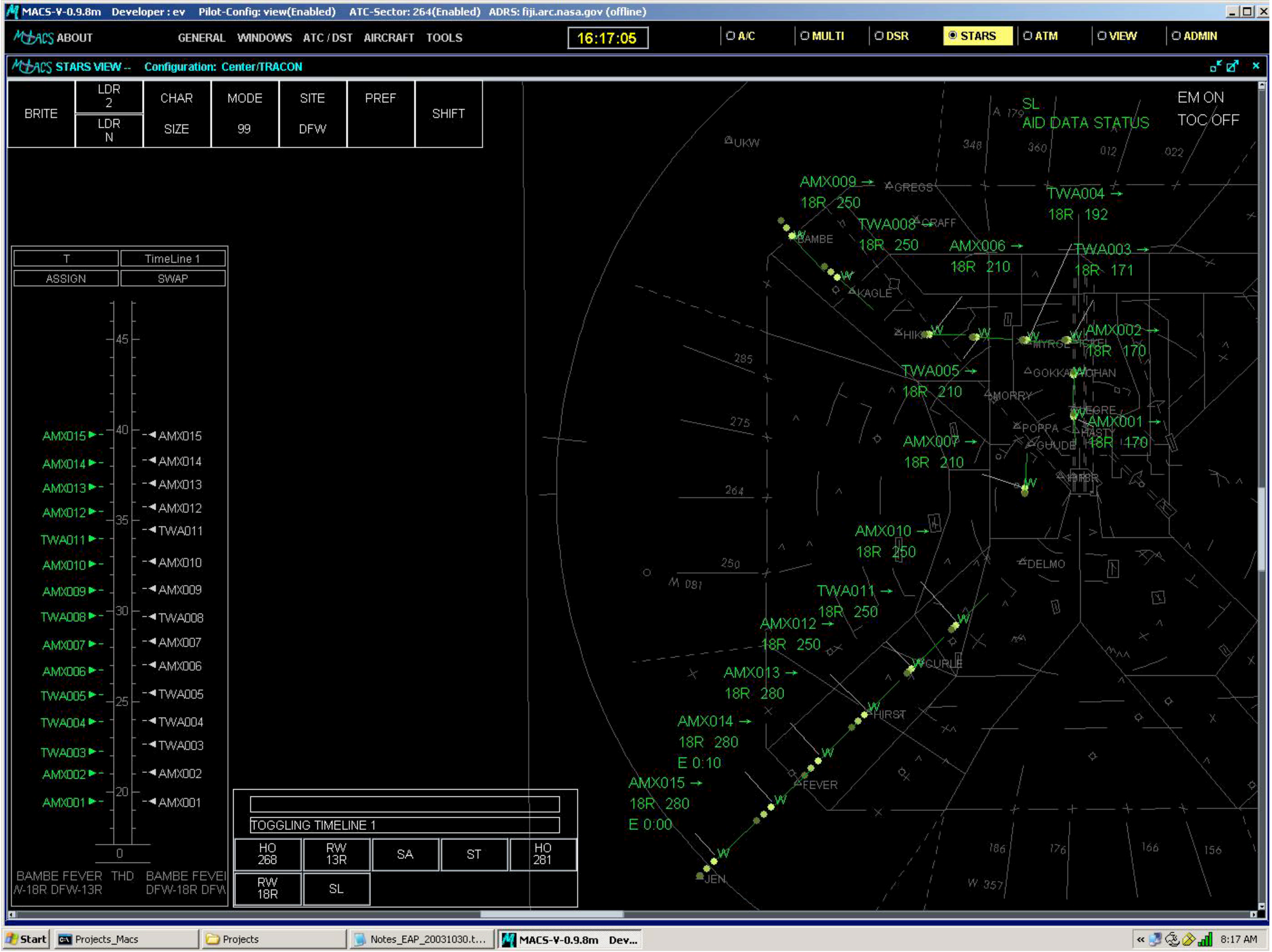
3-D Vertical Profile Display



Single Pilot Station



ACFS Flight Deck


MACS-V-0.9.8m Developer : ev Pilot-Config: view(Enabled) ATC-Sector: 264(Enabled) ADRS: fiji.arc.nasa.gov (offline)
ABOUT GENERAL WINDOWS ATC / DST AIRCRAFT TOOLS
16:17:05
A/C MULTI DSR STARS ATM VIEW ADMIN
STARS VIEW -- Configuration: Center/TRACON
BRITE
LDR 2
LDR N
CHAR SIZE
MODE 99
SITE DFW
PREF
SHIFT
SL
AID DATA STATUS
EM ON
TOC OFF
T
TimeLine 1
ASSIGN
SWAP
AMX015
AMX014
AMX013
AMX012
TWA011
AMX010
AMX009
TWA008
AMX007
AMX006
TWA005
TWA004
TWA003
AMX002
AMX001
BAMBE FEVER THD
BAMBE FEVER
TOGGLING TIMELINE 1
HO 268
RW 13R
SA
ST
HO 281
RW 18R
SL
AMX009 18R 250
TWA004 18R 192
TWA008 18R 250
AMX006 18R 210
TWA003 18R 171
AMX002 18R 170
TWA005 18R 210
AMX001 18R 170
AMX007 18R 210
AMX010 18R 250
TWA011 18R 250
AMX012 18R 250
AMX013 18R 280
AMX014 18R 280 E 0:10
AMX015 18R 280 E 0:00
UKW
GREGS
CRAFF
BAMBE
KAGLE
HIKE
MYRGE
GOKKA
MORRY
POPPA
GUUDE
DELMO
CURLE
HIRST
FEVER
JEN
Start
Projects_Macs
Projects
MACS-V-0.9.8m Dev...
8:17 AM

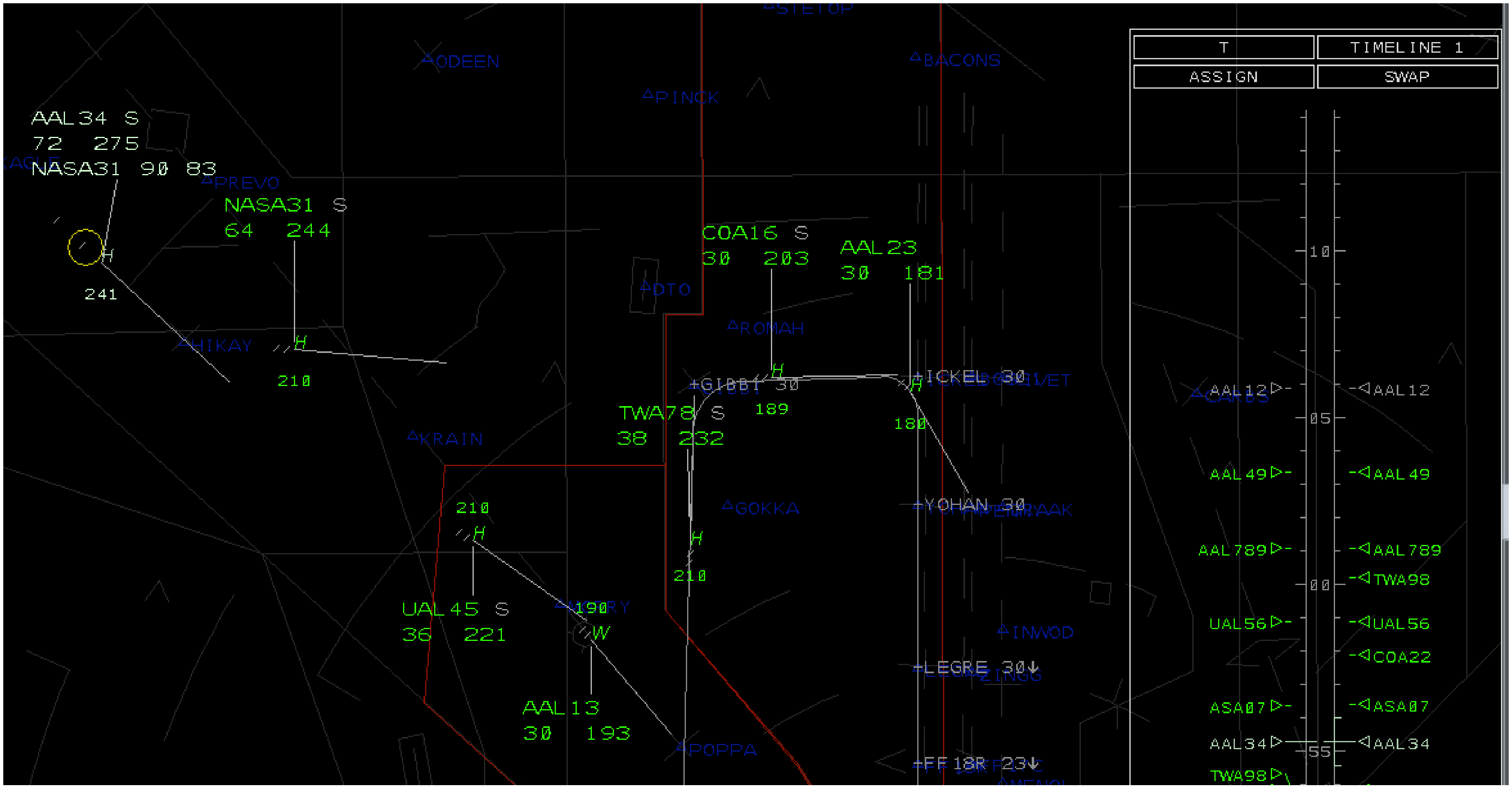
TRACON Controller Display with Spacing Advisories

Controller tools:

- Timeline with runway ETAs and STAs
- Spacing advisory
  - lead aircraft
  - spacing interval
  - estimated current spacing interval
- Spacing history circles
- Early/late display in datablock

ADS-B Surveillance & datalink:

- Accurate position, altitude, speed and track
- One second updates
- Display of indicated airspeed
- Display of FMS trajectory
- Downlinked FMS route



Radio Frequencies	
Feeder	119.87
Final	118.42
Ghost	129.0

HIKAY 18R (HIK18R) FMS Transition

	distance	altitude	speed
BAMBE	51nm	11,000’	250
KAGLE	42nm	-----	---
HIKAY	35nm	7,000’A	210
GIBBI	21nm	4,000’	---
ICKEL	15nm	3,000’A	180
YOHAN	12nm	3,000’	170

DELMO 18R (DEL18R) FMS Transition

	distance	altitude	speed
FEVER	80nm	11,000’	280
HIRST	69nm	11,000’	250
DELMO	45nm	8,000’	210
SILER	32nm	5,000’A	---
GIBBI	21nm	3,000’	---
ICKEL	15nm	3,000’	180
YOHAN	12nm	3,000’	170

Note: The crossing altitude at GIBBI is either 4000’ from HIKAY or 3,000’ from DELMO.

NASA 14 JUN 04

ATIS 123.77

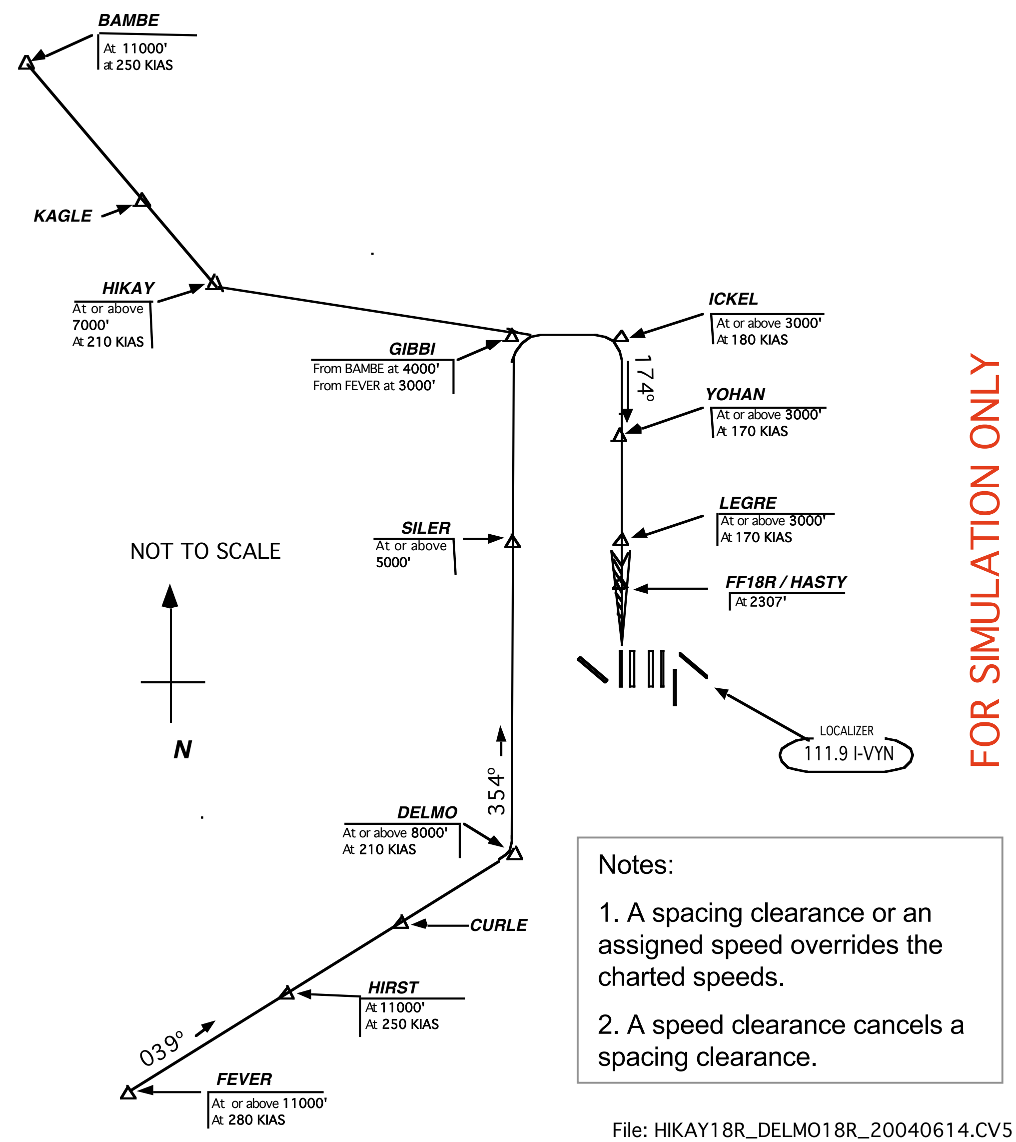
HIKAY and DELMO RW 18R FMS Transitions

DALLAS-FT WORTH, TEXAS

DALLAS-FT WORTH, INTL

HIKAY and DELMO Runway 18R FMS Transitions

(FOR USE BY SLANT E (/E) OR SLANT F (/F) AIRCRAFT ONLY)



Notes:

1. A spacing clearance or an assigned speed overrides the charted speeds.
2. A speed clearance cancels a spacing clearance.

File: HIKAY18R_DELMO18R_20040614.CV5

Clearance Information

- The initial TRACON clearance confirms FMS Transition and authorizes descent.

  “UAL123, After BAMBE, descend via the HIKAY 18R FMS Transition.”

  “UAL123, After FEVER, descend via the DELMO 18R FMS Transition.”

  “UAL123, After BAMBE, descend via the HIKAY 13R FMS Transition.”

- The “follow” or “merge behind then follow” clearance specifies lead aircraft and spacing interval.

  “UAL 345, follow AAL234, 80 second in trail.”

  “ UAL 123, merge behind then follow AAL345 - 80 second in trail.”

CE-11 Roles and Responsibilities

- Controller is responsible for separation
- Flight crew can be cleared to merge behind then follow a lead aircraft
- Controller can cancel a spacing clearance at any time by issuing a speed clearance, heading vector or clearing the aircraft to resume charted speeds.

A “follow” or “merge behind then follow” clearance is similar to a speed clearance. The pilot is to follow the speeds provided by the spacing guidance. If the spacing is not working out, the controller will intervene with a speed clearance or heading vector.

A communication to space behind an aircraft is a *clearance* not a *delegation of authority*.

Controller Strategy to Support the Concept

- Feeder
  - Deliver aircraft to the final on the FMS routes at:
    - DELMO or SILER from FEVER
    - HIKAY or GIBBI from BAMBE
  - Deliver aircraft on the Scheduled Times of Arrival (STAs)
    - work toward delivering aircraft on schedule
  - Clear properly setup aircraft to “follow”
- Final
  - Clear properly setup aircraft to “merge behind then follow”

Controller team goal: Deliver all aircraft after the first with minimum spacing without violating the spacing matrix at the final approach fix. The first aircraft should be left on the FMS route and landed first.

TRACON Traffic Feed

- The initial 13 aircraft are delivered to the BAMBE and FEVER meter fixes on a runway based schedule
  – Planned runways - either 13R or 18R - are preassigned
  – Aircraft are scheduled according to the wake vortex spacing matrix at the 18R runway threshold
  – The scheduled meter fix crossing times follow from the runway schedule
  – The aircraft are a mix of LARGE, B757 & HEAVY weight classes
  – Aircraft cross the meter fixes within approximately 40 seconds of scheduled time

- The final 9 aircraft are NOT delivered to the BAMBE and FEVER meter fixes on a runway based schedule
  – Planned runways - either 13R or 18R - are preassigned
  – Aircraft are delivered to the meter fixes approximately 7 miles in trail

	TRAIL LARGE	TRAIL HEAVY	TRAIL B757
LEAD LARGE	80 sec	80 sec	80 sec
LEAD HEAVY	120 sec	100 sec	100 sec
LEAD B757	100 sec	100 sec	100 sec

CE-11 Experiment Conditions

Condition	Ground Tools	Air Tools
1	No	No
2	No	Yes
3	Yes	No
4	Yes	Yes

In the air tools condition, approximately 75% of the aircraft were equipped for spacing.

All of the aircraft included in this presentation were equipped for spacing.

CE-11 Experiment Schedule

Training	2 days

Day 1 – separate air and ground training
- Briefing
- Runs with no tools
- Lunch
- Runs with air and ground tools
- Last run with combined air and ground

Day 2 – combined air and ground training
- Runs with ground tools only
- Runs with air tools only
- Runs with air and ground tools

Data collection	5 days

- 8 runs per day

Backup / Questionnaires	1 day

Test Matrix: Conditions

Time	Session	Day 3 Th	Day 4 F	Day 5 M	Day 6 Tu	Day 7 W
8:15 - 9:45	Scenario 1 *Run1* *Run2*	N	A	GA	G	N
10:00 -11:30	Scenario 2 *Run3* *Run4*	G	N	A	GA	G
12:45 - 2:15	Scenario 3 *Run5* *Run6*	A	GA	G	N	A
2:30 - 4:00	Scenario 4 *Run7* *Run8*	GA	G	N	A	GA

N: No Tools
G: Ground Tools
A: Air Tools
GA: Ground and Air Tools

Controllers swap positions between Feeder and Final after each run.

Test Matrix: Controller Teams

Test bed	Day 3 Th	Day 4 F	Day 5 M	Day 6 Tu	Day 7 W
SONY-H302	Controller 1 Controller 2	Controller 2 Controller 3	Controller 3 Controller 4	Controller 4 Controller 1	Controller 1 Controller 3
BARCO-H200	Controller 3 Controller 4	Controller 4 Controller 1	Controller 1 Controller 2	Controller 2 Controller 3	Controller 3 Controller 4

All controllers work all positions in all scenarios and conditions.
All controllers interact with all pilots in the course of the study.

Scenarios

- **1 pace aircraft**
- **12 main flow aircraft**
  - These aircraft provide the experiment data on nominal spacing precision
  - These aircraft include the single pilot and ACFS simulators
  - piloted simulators flew each merge/follow variation: BB, BF, FB, FF
  - The en route feeds to runway 18R over the two meter fixes are coordinated
- **9 secondary flow aircraft**
  - These aircraft provide a traffic problem designed to test the robustness of the concept
  - The en route feeds to runway 18R over the two meter fixes are not coordinated

Runs were stopped after 35 minutes.

Environment

Winds:

Altitude	Direction	Speed
40,000	250	50
30,000	240	40
20,000	270	30
10,000	280	20
5,000	230	15
0	180	10

Visibility: IMC

Research Hypotheses

1. Using ground-side tools will result in more precise spacing and less vectoring.

2. Using air-side spacing tools will result in more precise spacing and less vectoring.

3. Using both air and ground tools will result in the most precise spacing and the least vectoring.

4. Aircraft equipped with spacing guidance and ADS-B information can control arrival spacing more precisely than controllers.

5. Operations in which equipped aircraft can be cleared to merge behind and then follow another aircraft will be operationally acceptable to pilots and controllers.

6. Operations with a mix of equipped and non-equipped aircraft are operationally acceptable.

7. Controllers will be able to cope with flow upsetting events and uncoordinated arrival flows with tools.

8. Controller workload will be less with ground spacing tools and when aircraft are equipped for spacing.

Benefit mechanism: Aircraft equipped with spacing guidance and ADS-B information can fine-tune spacing more accurately than a controller.

CE-11 DAG-TM Spacing and Merging - Pilot Post Simulation Questionnaire

- At completion of the simulation, the pilots were asked to complete a questionnaire.
- The questionnaire was divided into eight sections, each section contained questions relating to particular aspects of the concept.
- Most questions were formatted with responses based on a Likert scale.

Sample Question

	Strongly disagree (1)	Somewhat disagree (2)	Neither disagree nor agree (3)	Somewhat agree (4)	Strongly agree (5)	Not applicable / Did not use
I believe the merging and spacing procedure would be acceptable in a two pilot crew environment:	○	○	○	○	○	○

Numbers in parenthesis are the scoring values assigned for analysis

Eight topics covered in the questionnaire:

- **General/Operations**
- **Spacing and Merging**
- **Safety of Flight**
- **Display Features**
- **Call-sign Procedures**
- **Training**
- **Simulation Environment**
- **Overall Comments**

Questionnaire Stats

- There were a total of 531 possible responses to the scaled questions.
- Two questions each had one response missing.
- 90.9% of responses were with a rating equal to or better than average.
- To make the rating easier for the pilots, they were instructed to assume that a rating scale of ‘3’ (average) represented ‘normal operations’.

General / Operations

- The pilots were asked to report their level of acceptance of the spacing and merging concept.

- They were also asked to report their opinion of the operational requirements for using the CDTI.

General / Operations Results

- The pilots 'strongly agreed' (x = 4.79) that the merging and spacing procedure would be acceptable in a two-crew pilot environment.
- With appropriate training, the pilots 'strongly agreed' (x = 4.67) they would be comfortable flying this procedure.
- The pilots 'somewhat agreed' (x = 4.00) that any increase in head-down time beyond that currently experienced would most likely be acceptable considering the information gained from the CDTI.

Spacing and Merging

- On simulation runs where the aircraft utilized the on-board CDTI, pilots were asked to merge and/or space behind a lead aircraft.
- Merging and spacing was accomplished by engaging the CDTI spacing tool.
- Spacing was time-based (i.e. 60sec, 90sec, 120sec).
- Spacing assignment was based on type of aircraft assigned to follow.

Spacing and Merging Results

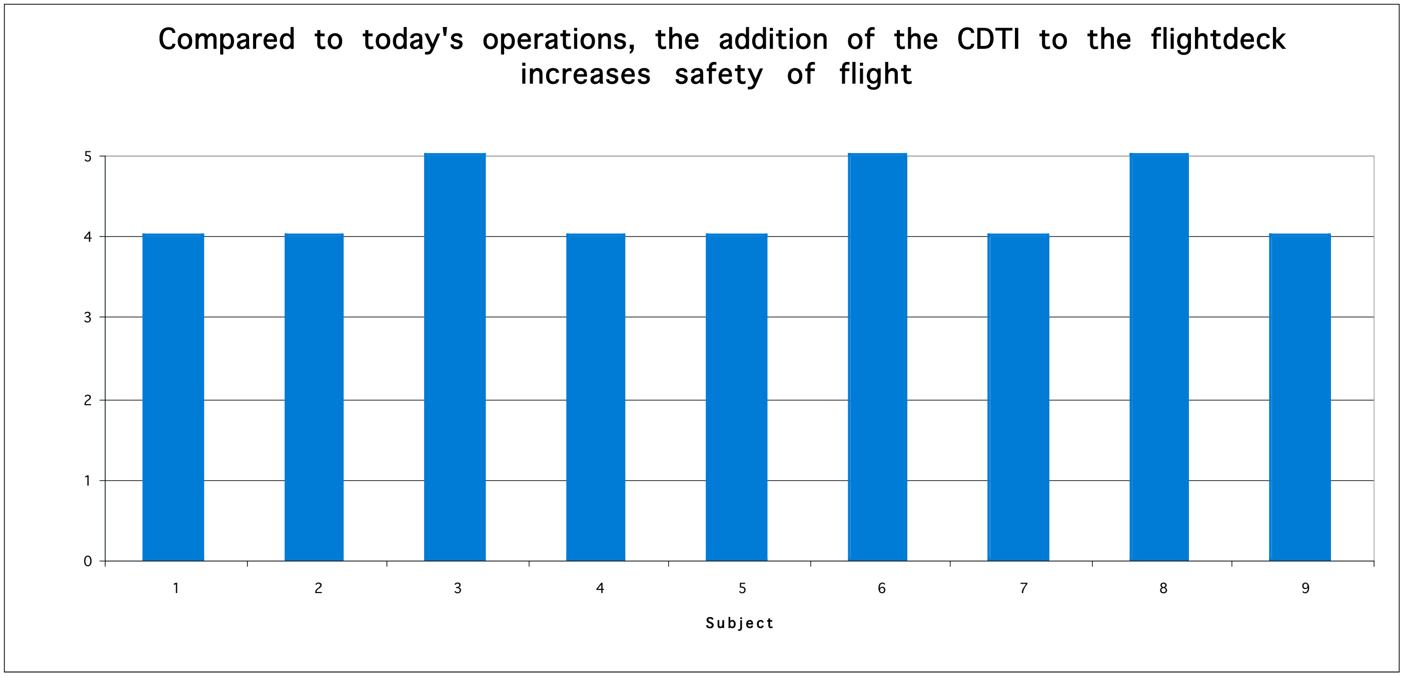
- The pilots *'strongly agreed'* (x = 4.78) that they would be willing to accept a spacing assignment by reference to the CDTI and no visual contact.
- The pilots *'somewhat agreed'* (x = 3.67) to accept a modification of the meaning "visual separation", provided the necessary rule or guidance changes were made, to include the use of the CDTI.
- The pilots *'somewhat disagreed'* (x = 1.78) that initial visual acquisition of the lead aircraft should be required prior to using the CDTI for spacing.

Safety of Flight

The CDTI will improve safety of flight by increasing situational and traffic awareness by providing the flight crew with accurate, timely and integrated information on the traffic situation.

As we continue to integrate terrain, weather and special use airspace into the display we will better address the safety of flight issues as identified by the Flight Safety Foundation - controlled flight into terrain, the approach and landing phase of flight, loss of control, and human factors.

Safety of Flight



Safety of Flight Results

- The pilots *'somewhat agreed'* (x = 4.33) that the addition of the CDTI would increase the safety of flight.
- In the arrival and approach phase of flight, the pilots *'somewhat agreed'* (x = 3.78) that the use of the CDTI will enhance the safety of the operations.

Display Features

- The pilots were asked to evaluate the CDTI features they used during this simulation.
- All the pilots had experience using the CDTI during the DAG-TM CE-5 simulation.
- Many of the CDTI tools used in CE-5 were not used in CE-11.

Display Feature Results

- The pilots were *neutral* when questioned if the symbols were acceptable as is (x = 3.44).
- The pilots *'somewhat agreed'* that the symbol color scheme was acceptable as is (x = 4.33).
- The pilots *'somewhat agreed'* (x = 3.89) that the information provided in the data tag was useful for performing the spacing and merging task and that the information was easy to find (x = 4.00).

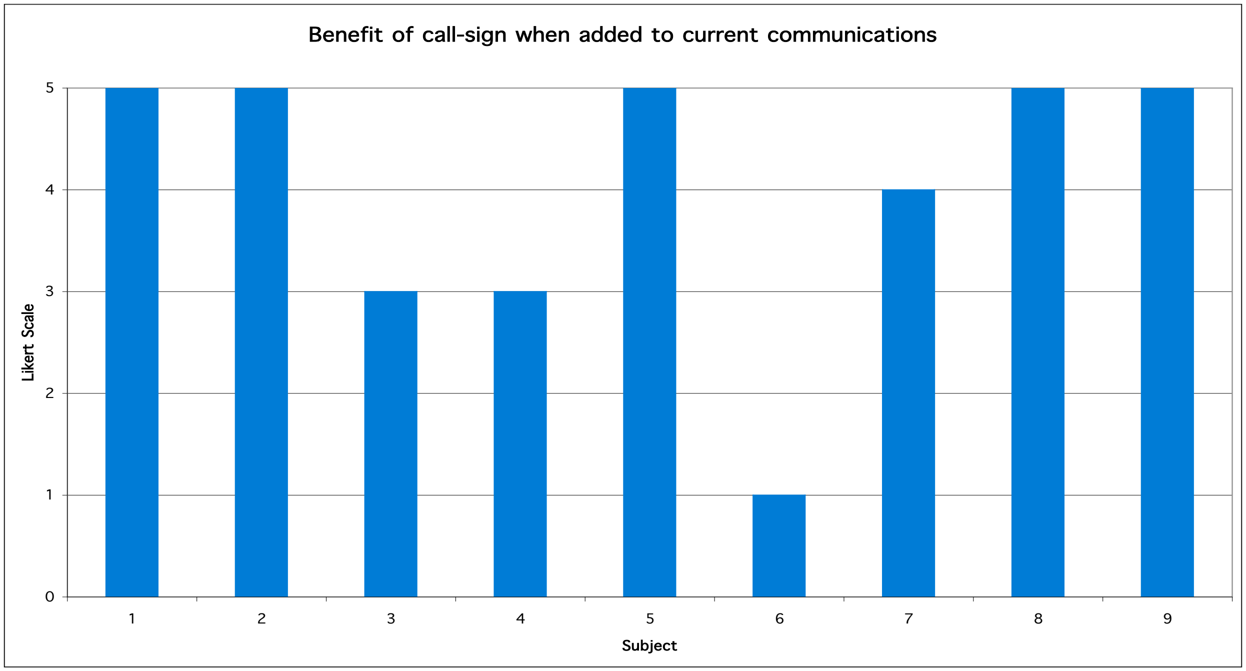
Call-sign Procedure

"UAL123, merge behind then follow AAL345 – 90 seconds in trail"

"UAL123, follow AAL345 – 90 seconds in trail"

- It was initially thought that the use of two call-signs in one radio transmission would be confusing to the pilots of each aircraft.

Pilot Response



Call-sign Procedure Results (con't)

- When asked if the additional call-sign made communications difficult, the pilots 'somewhat disagreed' (x = 1.7)
- The pilots 'somewhat agreed' (x = 4.0) that the benefits gained in the use of other aircraft call signs, when added to current communications, were worthwhile.
- "No problem. Most often I had already identified."
- "Easily accomplished."

Training

- All participating pilots had extensive classroom training.
- All participating pilots participated in the DAG-TM CE-5 Simulation Study.
- Training material included: a CDTI User's Manual, a procedural handout and a CDTI DFW arrival chart.

Training Results

- The pilots *'somewhat agreed'* (x = 3.56) that the classroom training they received was understandable and accurate.
- The pilots *'strongly agreed'* (x = 4.33) that the training material they received was understandable and accurate.
- The pilots *'strongly agreed'* (x = 4.78) that after training, they fully understood how to do the merging and spacing tasks.
- "Maybe use a 'real-time' video."
- "Far less training is necessary."

Simulation Environment

- Seven single pilot PC stations
- Advanced Crew Flight Simulator
- Four active air-traffic controllers
- Twelve pseudo-pilots

Simulation Environment Results

- The pilots *'strongly agreed'* (x = 4.78) that as implemented in our simulation, the CDTI was usable.
- The pilots also *'somewhat agreed'* (x = 4.22) that ATC, as experienced in this simulation, was an acceptable representation of the real world.
- Pilots reported that there were aspects of the simulation that made it artificially difficult: speed algorithm and resulting flap manipulations.
- Pilots reported that there were aspects of the simulation that made it artificially easy: no out the window for the pilots at the PC stations, no jeopardy for over speeding the aircraft.

Pilot Comments

During the course of the simulation, what techniques did you find effective to successfully merge and/or space behind the lead aircraft?

- "Identify probable lead aircraft ahead of time"
- "Manual manipulation of the speed…"
- "I found pulse-predictors very useful for identifying lead aircraft…"

Pilot Comments (con't)

In general, is the CE-11 procedure acceptable to you?

- "Wonderful tool, absolutely a must for future airspace expectations."
- "It's hard for me to answer without using the tools in a real cockpit."
- "I think it's acceptable. I'm sure it's much more effective for time and space of use."

Pilot Comments (con’t)

What recommendations would you make for improving the concept?

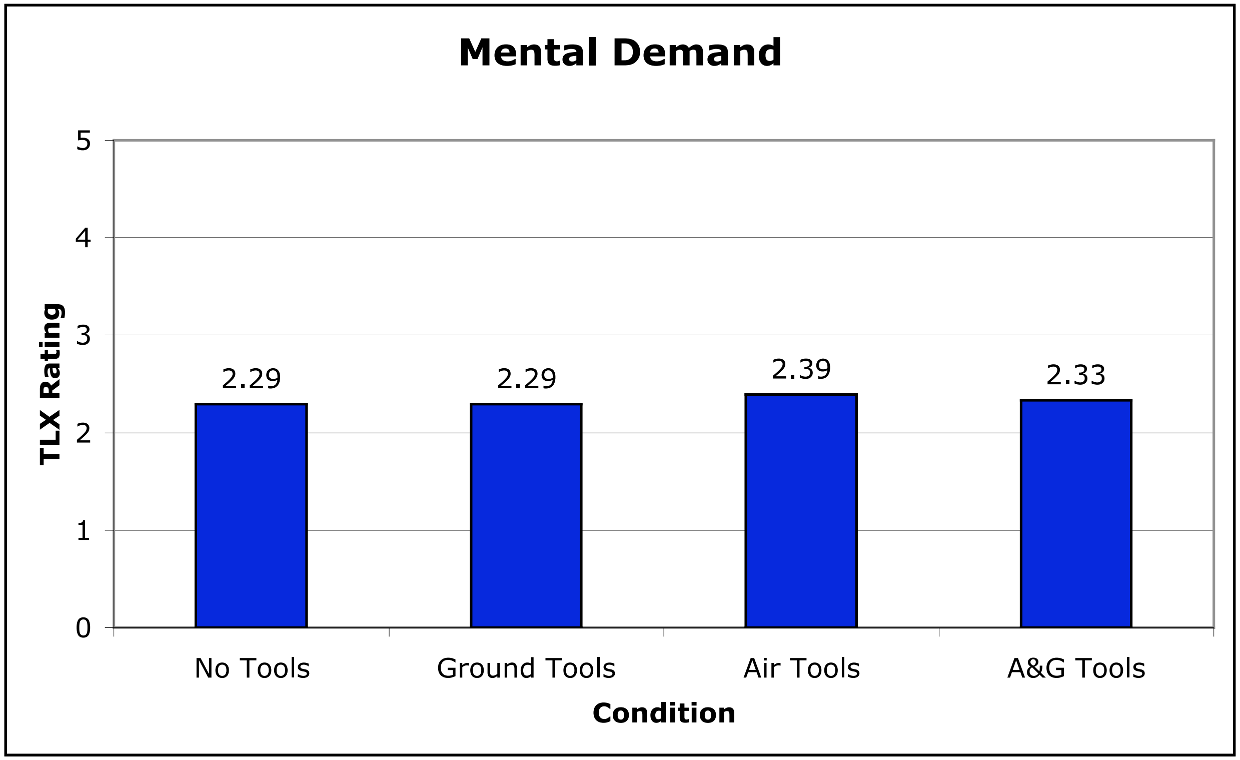
- “Adding more realism to <the single pilot> computers i.e. warnings for flap settings.”
- “Adjust speed commands in spacing mode.”
- “Further trial runs with pilot participation.”
- “…the use of trend indicators.”
- “Each pilot should have minimum two days of training in the ACFS…”

Merging and Spacing Workload

- Pilots were asked to complete a modified NASA TLX workload rating after each simulation run.
- Mental demand, performance, effort, level of frustration, temporal demand, peak workload (causal event) and overall workload were rated.
- Events were rated on a scale of 1 (low) to 5 (high) with ‘3’ being equal to normal operations.

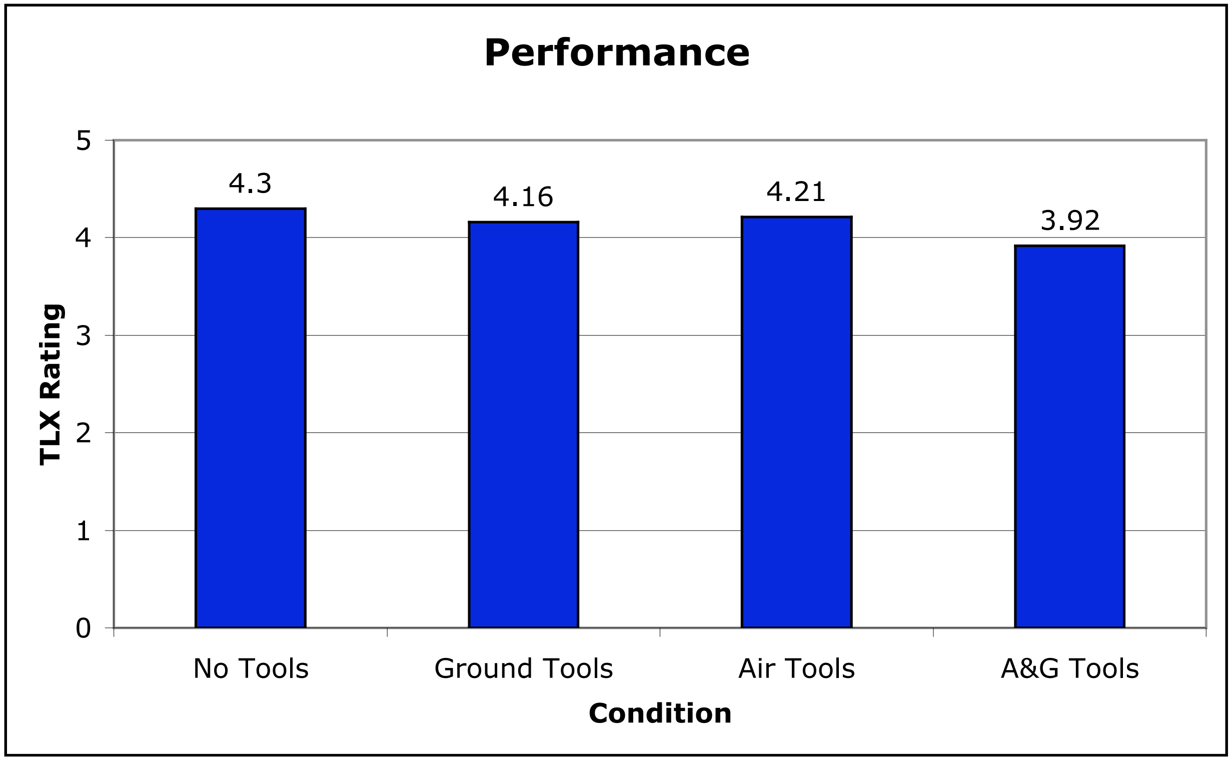
Mental Demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering)



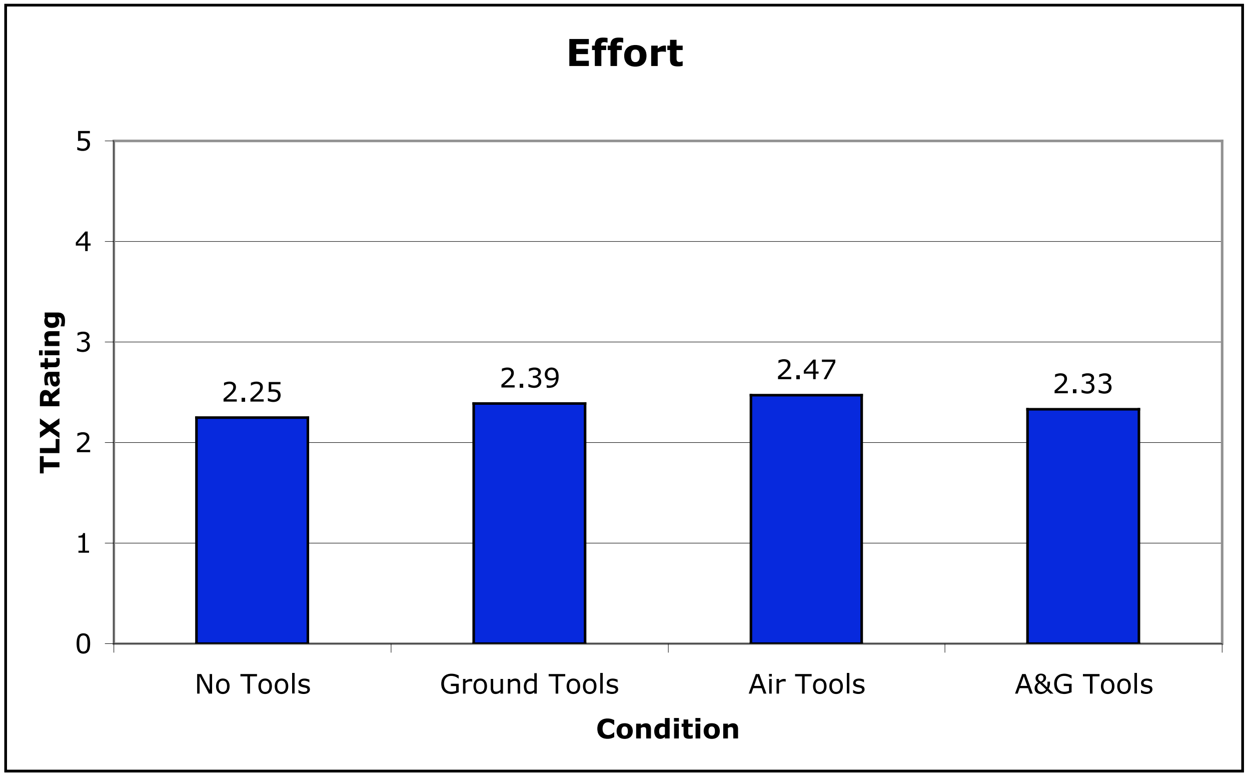
Overall Performance

(How successful do you think you are with your performance in accomplishing your goals)



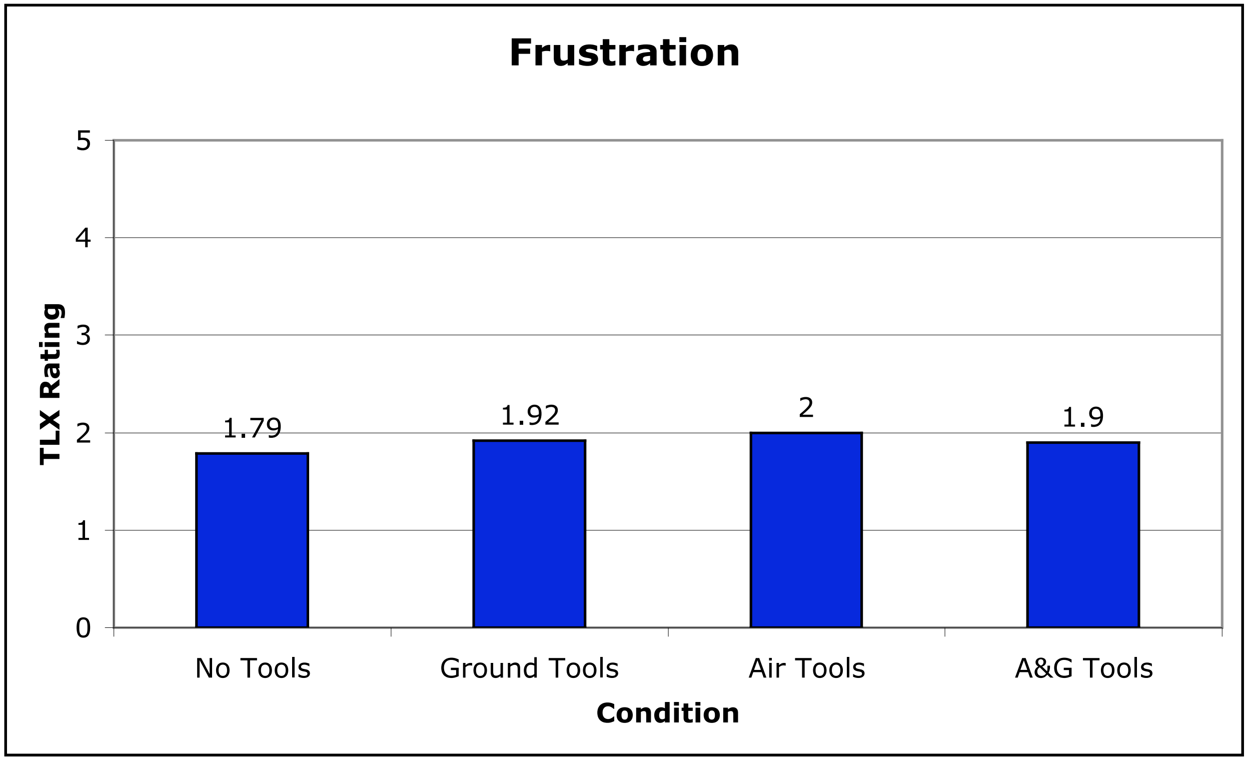
Effort

How hard did you have to work - mentally and physically - to accomplish this level of performance



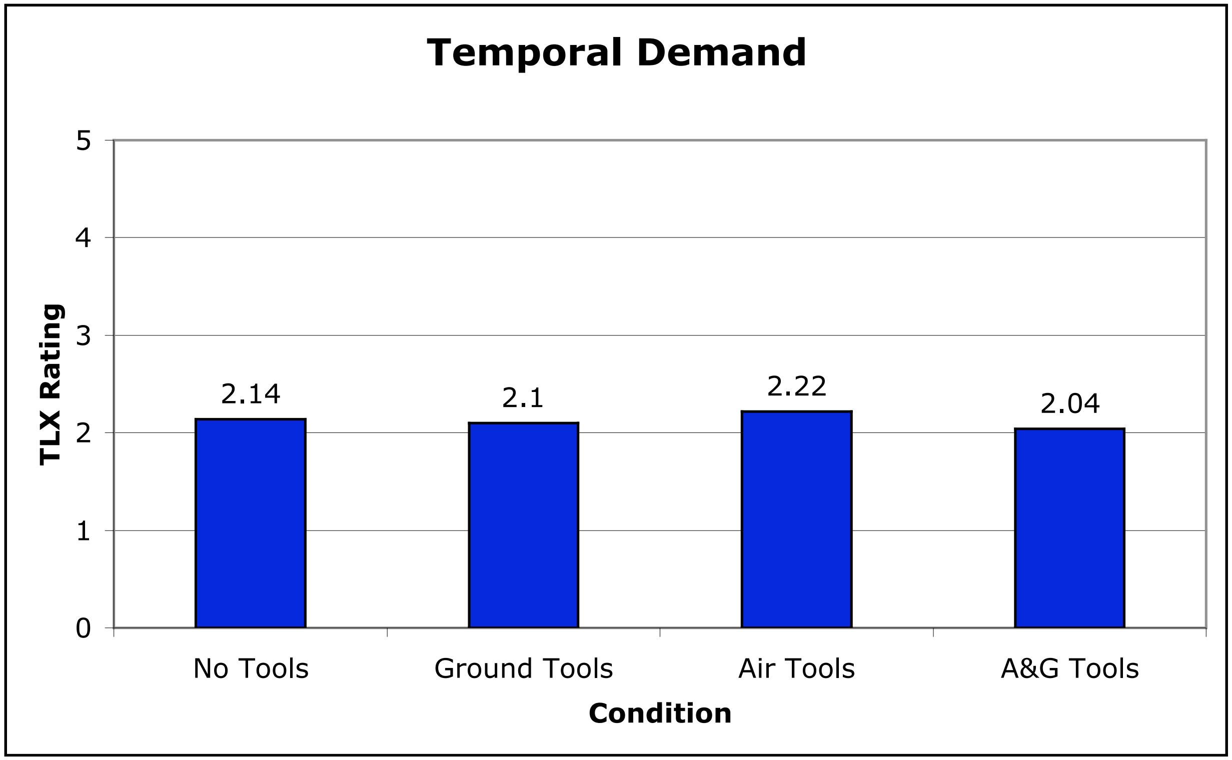
Level of Frustration

How irritated, stressed and annoyed versus relaxed and at ease you feel performing the task

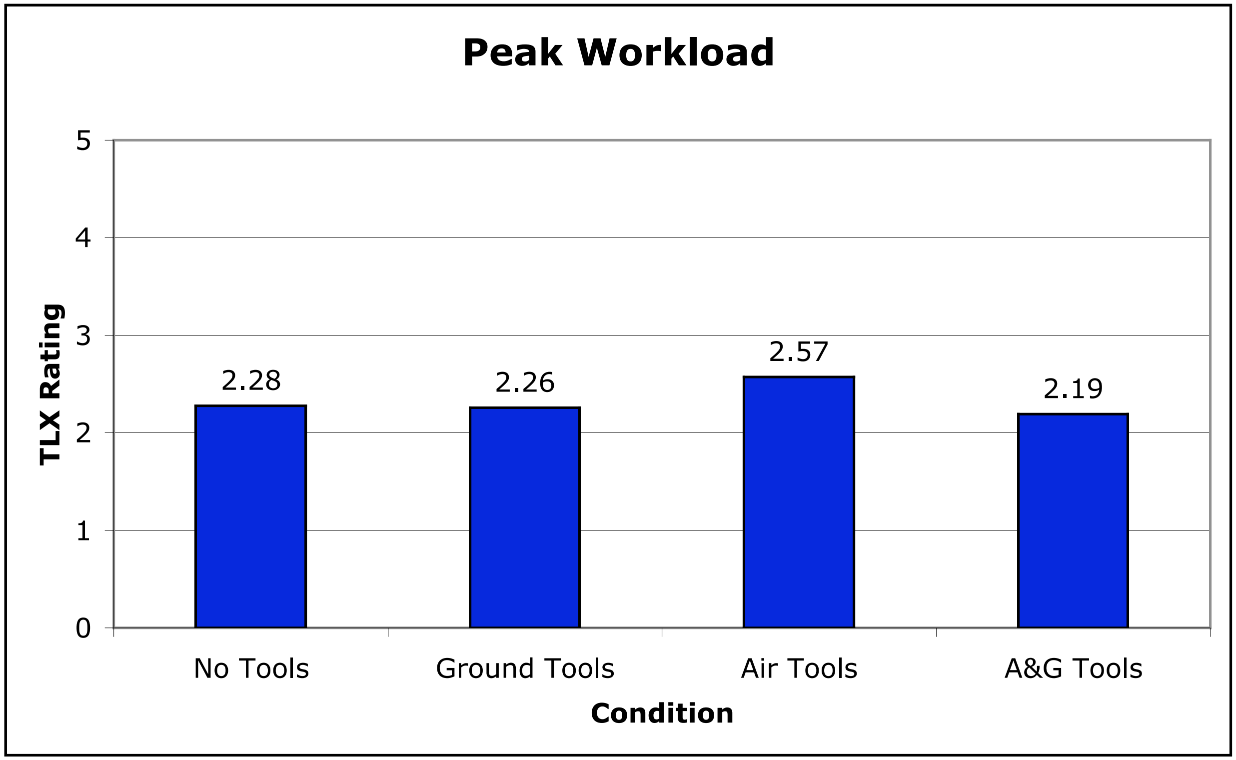


Temporal Demand

How much time pressure did you feel due to the rate or pace at which the tasks occurred



Peak Workload

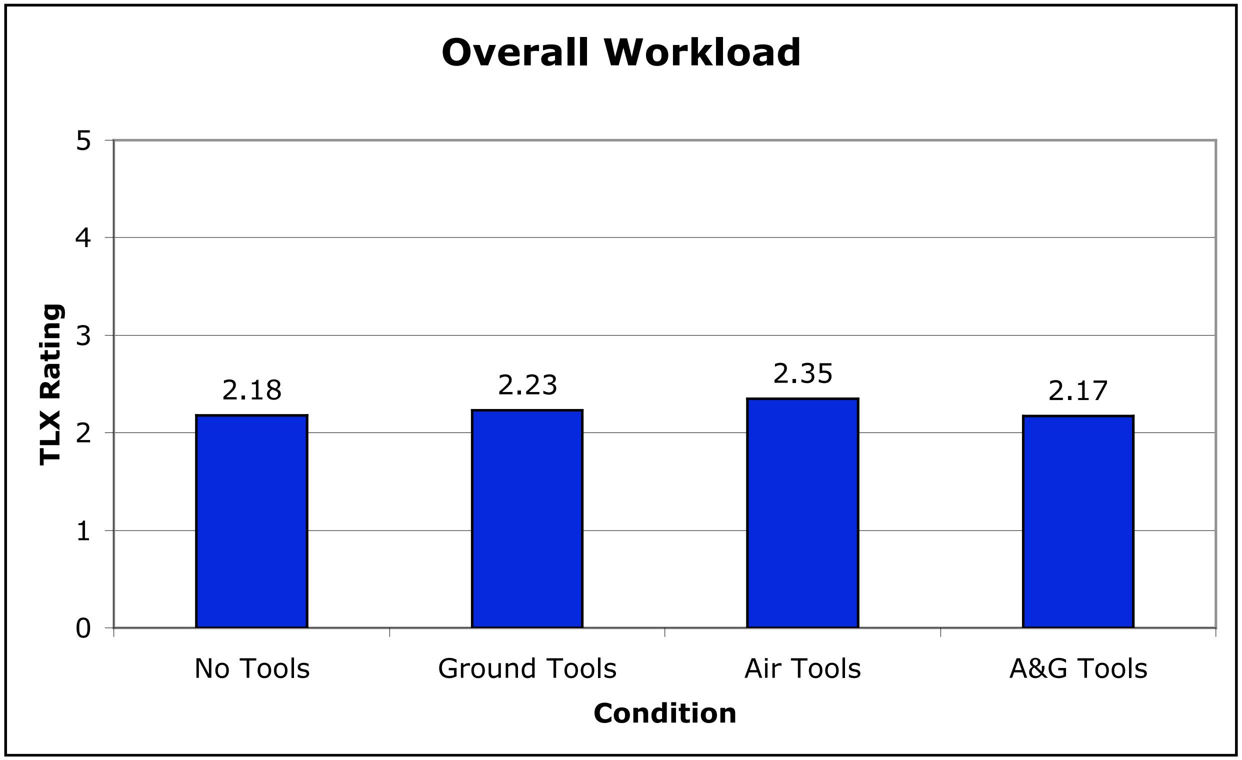


Peak Workload Events

Technical Problems	5
After specified waypoint	8
Other	9
Monitoring	9
Final Approach	10
Vectored on Final	11
No Peak Event	14
Spacing Task	15
Speed Adjustments	26

The Peak Workload Events were evaluated for commonality and divided into general categories for analysis.

Overall Workload



Summary Remarks

- Pilot suggested that the concept of merging and spacing seems viable and feasible.
  - Issues:
    - Approach spacing algorithms
    - Better flight deck integration
    - Controller and pilot procedures and training
- Pilot also suggested that flight deck systems could have a positive impact on situational awareness, safety, and workload

END